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"How Should I Know What Scientists Do?—I Am Just a Kid": Fourth-Grade Students' Conceptions of Nature of Science

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The purpose of this study is to explore elementary students' views of (NOS) to see how well they align with national reform recommendations (AAAS, 1993; NRC, 1996). Using an open-ended questionnaire coupled with one-on-one interviews of fourth-grade students conducted at the end of the school year, the researchers explored students' understandings of the distinction between observation and inference, the creative and imaginative nature of science, and the tentative yet reliable nature of science. Through interpretive analysis of student responses, the researchers describe students' views of NOS and compare them to reform recommendations for NOS understandings.

Introduction

The *National Science Education Standards* (National Research Council [NRC], 1996) and *Benchmarks for Science Literacy* (American Association for the Advancement of Science [AAAS], 1993) recommend that elementary students develop an understanding of how scientists go about their work in terms of understanding science as inquiry as well as the nature of science (NOS). From the earliest grades (K-2), the *Benchmarks* recommend that students not only "gain lots of experience *doing* science" but they should also be taught about "how the science community arrived at those conclusions" (p. 4).

In their NOS position statement, the National Science Teachers Association (NSTA) (2000) recommends that science, along with its methods, explanations and generalizations, must be the sole focus of instruction in science classes. Their position on what teachers and students should know includes that (1) scientific knowledge is both reliable (one can have confidence in scientific knowledge) and tentative (subject to change in light of new evidence or reconceptualization of prior evidence); (2) no single scientific method exists, but there are shared characteristics of scientific approaches to science such as scientific explanations being supported by empirical evidence and that they are testable against the natural world; (3) creativity plays a role in the development of scientific knowledge; (4) there is a relationship between theories and laws; (5) there is a relationship between observations and inferences; (6) though science strives for objectivity, there is always an element of subjectivity in the development of scientific knowledge; and

(7) social and cultural context also play a role in the development of scientific knowledge. It is these NOS elements which were the focus of the present study. The *National Science Education Standards* (NRC, 1996) and *Benchmarks for Science Literacy* (AAAS, 1993) also recommend similar understandings for elementary students.

For this study, we focused on exploring the meanings fourth-grade students ascribed to three of the recommended understandings: (1) the tentative yet reliable nature of science; (2) the creative and imaginative nature of science; and (3) the distinction between observation and inference, with the idea that to design suitable instruction to help elementary students develop appropriate understandings of NOS that are in line with the educational reforms, it is first desirable to explore their current understandings of NOS. Additionally, the teacher whose class we interviewed indicated that she believed her students should be able to readily discuss their ideas about the selected topics. We wondered what is it that elementary students currently understand about NOS as compared to what the standards recommend that they know.

Statement of the Problem

It has been found in previous studies that elementary teachers do not usually have informed views of NOS (e.g., Abd-El-Khalick & Akerson, in press; Akerson, Abd-El-Khalick, & Lederman, 2000; Akerson, Morrison, & Roth McDuffie, 2003; Gallagher, 1991; King, 1991; Lederman, 1992). Extrapolating that teachers cannot possibly teach what they do not know, it would not be surprising to find that their students do not have a good understanding of NOS elements. The current study proposes to describe fourth-grade students' understandings of NOS elements recommended by the reform documents at the end of a school year when taught science by a teacher with appropriate NOS conceptions (Akerson & Abd-El-Khalick, 2003). The specific research question is "What are fourth-grade students' conceptions of NOS after participating in science for one school year by a teacher with informed NOS conceptions?" Again, for this study, we focused on fourth-grade students' views of NOS with respect to the tentative NOS, the creative and imaginative NOS, and the important distinction between observation and inference.

Review of Previous Studies Exploring Students' NOS Conceptions

A review of literature that describes pre-college students' NOS conceptions uncovers several studies at the high school level, and only two at the sixth-grade elementary level. We were unable to find any studies at lower elementary grade levels. Indeed, Smith, Maclin, Houghton, and Hennessey (2000) agree that we know little about elementary schoolchildren's current NOS views and call for more exploration of their ideas. Given that it is likely that elementary students do not hold views similar to those recommended in the reform documents (e.g., AAAS, 1993), we need to explore what students actual conceptions of NOS are to help them improve their current understandings. Below we will review other studies that describe pre-college students' NOS conceptions.

In a study of eleventh- and twelfth-grade students in an environmental science class, Moss (2001) found that while students understood that scientific knowledge changes, they did not recognize that science was stable and that it arose from many different kinds of methods. Rather, he found that these students believed

that all scientific knowledge arose from a prescribed method such as the scientific method. He also found that these students believed that science is "everything," that there was no distinction between science and other disciplines other than using a specific method (scientific method) to uncover information.

Meichtry (1993) found that middle school students' views of NOS did not change despite immersion in a scientific inquiry program (Biological Sciences Curriculum Study [BSCS]). She found that students' understandings of the creative, tentative, and empirical NOS were not adequate. Students who participated in an inquiry program decreased their understandings of the developmental and testable NOS, and those who participated in a "traditional" program decreased their understandings of the creative NOS. Similarly Khishfe and Abd-El-Khalick (2002) found that sixth-grade students in an implicit, inquiry instruction group did not change their views of NOS, and most held inadequate views of the tentative, empirical, creative, and imaginative NOS. These students were unable to distinguish between observation and inference. In another study of sixth-grade students, Smith et al. (2000) found that students who had been in an inquiry classroom for six years with the same teacher held more informed NOS views in the areas of empirical testing, collaborating with colleagues, making explanations, and developing ideas. The authors forward the explanation that perhaps being immersed in an inquiry classroom for all of their science instruction gave them a more intense inquiry experience. In addition, the kinds of discourse in which the teacher and students participated allowed them to better negotiate understandings of nature of science.

BouJaoude (1996) conducted a study of 572 high school students in Lebanon. He found that most of these students held inadequate NOS views and believed that science was a collection of subject areas, that theories do not influence observations, that hypotheses become theories and then laws, and that laws are discovered not invented. They also believed that there was a definite scientific method. In a comparative study of three countries, Griffiths and Barman (1995) similarly found that the 96 high school students interviewed in these countries held inadequate views of NOS, believing that a definite scientific method existed; that science is certain, not tentative and subject to change; and that laws are mature theories with more evidence.

Design and Procedures

The participants were 23 fourth-grade elementary students in a self-contained classroom whose teacher had informed views of NOS (Akerson & Abd-El-Khalick, 2003). Ten students were male and thirteen were female. Nine were second language learners. Their teacher taught science nearly every day of their school year for about an hour each day. Their teacher also used other periods in the class to explore science. For instance, she encouraged them to read about science topics from trade books during reading time. The teacher engaged the students in meaningful scientific inquiries such as allowing them to design water quality tests and investigations, and allowing them to raise their own related questions to science topics they were studying in class. She intended for the scientific inquiries and investigations to not only help students improve in their science content understandings but also to help her students understand the NOS. Thus, she intended to implicitly teach about NOS as well as scientific content through inquiry during her science lessons throughout the school year. (For more information regarding her teaching approaches, see Akerson and Abd-El-Khalick, 2003.)

Data Collection

At the end of the school year all 23 students completed a modified *Views of Nature of Science—Form B* (Lederman, Abd-El-Khalick, Bell, & Schwartz, 2002) questionnaire (see Appendix). The *VNOS-B* was modified to focus on the NOS aspects being explored in this study. A content specific item was added (number 3) that explored students' NOS views of observation and inference in the context of content they were studying in class. Students were asked to fill out the open-ended questionnaire, which was designed to provide information assessing elementary students' conceptions of NOS as they align with recommendations in the *Standards.* Then, eight students were purposively selected for follow-up interviews. These students were evenly matched in terms of gender and achievement levels in their class. They were individually interviewed in a quiet area outside the classroom. They were provided with copies of their completed questionnaires and asked to elaborate on their responses to provide more information and to help the researcher ensure a valid interpretation of student responses. These 45-minute interviews were audio-taped and transcribed verbatim for analysis.

Data Analysis

We analyzed pre-instruction interview transcripts and corresponding modified *VNOS-B* questionnaires separately to generate profiles of the students' views of NOS aspects, then compared both sources to ensure the validity of the questionnaire responses. This analysis indicated that our interpretations of the students' NOS views as described in the questionnaire were congruent to those expressed by the students during individual interviews. This congruency allowed us to proceed with data analysis.

We analyzed all the modified *VNOS-B* questionnaires to generate profiles of students' views. In this analysis, each participant was treated as a separate case. Data from each questionnaire was used to generate a summary of the students' views of NOS related to the seven target aspects. This process was repeated for all the questionnaires. We categorized student responses and conceptions as "adequate" if their responses indicated they had a view in line with the NSTA NOS position statement. For example, if a student responded that "science changes from time to time because you get more data," the response was coded as "adequate view of tentative nature of scientific theories." If the student responded that "science never changes because you already proved it," the response was coded "inadequate view of tentative nature of scientific theories." After this initial round of analysis, we searched the generated summaries for patterns or categories such as the numbers of students with adequate or informed understandings of target aspects, or if students had erroneous views, what were the patterns of error. The generated categories were checked against confirmatory or otherwise contradictory evidence in the data and were modified accordingly. We conducted several rounds of category generation, confirmation, and modification to satisfactorily reduce and organize the data.

Results

In the following, we describe the fourth-grade students' conceptions of nature of science with regard to the aspects of tentativeness, observation vs. inference, and imagination and creativity. A comparison is made between what the students

understand about NOS with what is recommended by the educational reforms. All names used are pseudonyms.

Observation Versus Inference

The distinction between observation and inference seemed to be the most informed view that students held of the aspects explored. In responses to how scientists knew that dinosaurs existed (Question 2), most students (22) believed that scientists used evidence (generally by looking at dinosaur bones and fossils) to induce what dinosaurs looked like. For example, one typical response was “The scientists find the bones of dinosaurs. That’s how they know they existed.” It was apparent that students believed that scientists did not “fill in” the gaps of the fossils they found. They thought scientists found all of the bones from a dinosaur and put them together “like Legos without directions.” For example, one student stated “they found the bones and kept finding them until they found all the bones for the body.” In the follow-up interview with this student, it seemed she truly believed that scientists found all of the bones for the dinosaur and that is when they knew it was a dinosaur. Only one student responded in a way that indicated she thought that though we had fossil and bone evidence of dinosaurs, that people had also seen dinosaurs and, thus, that is how scientists knew dinosaurs existed:

> *Because it came from cavemen who saw them and told lots of other ancestors, and then to us. That is how I think scientists think dinosaurs existed. Not just that they got the fossils from the dinosaurs but that someone saw them, too.*

In response to the second part of the question in which they were asked to describe how scientists could tell the color of dinosaurs, students did not seem to recognize the role of inference. One student stated, “They look up on the computer and get the answer.” Twelve students believed that scientists could infer the shape of the dinosaur by putting the bones together, but they would still have no idea about the color of the skin. For example, Tony responded, “Well, they know the shape because they have the bones. They just guess about the color of the skin; they keep trying different colors until it ‘looks right.’” One student, however, seemed to have a fairly informed view of how scientists infer the skin color of dinosaurs. She stated,

> *You don’t see a red or blue animal, so they pick the colors of animals that are alive today. They are predicting what the animal looks like based on evidence from today’s animals. So they pick a color that makes sense.*

Question 3 was an observation and inference question that was geared to contextualize students’ conceptions of observation and inference in a content area they studied in their class. They spent much time in class describing and drawing models of the inside of the earth, as well as talking about the kinds of evidence scientists used to develop those models. In response to how scientists determined what the inside of the earth looked like, most responses (19) were in the categories of “They dug into the earth” or “[They] used special telescopes [or microscopes, or computers/cameras].” Thus, for this question, despite instruction, 19 of the 23 students held the view that the scientists had to see the inside of the earth with either their eyes (by going inside the earth) or extensions of their senses using

technology to view the inside of the earth. Two other students simply stated that "Scientists do not know what it is like inside the earth.

Two students did recognize the role of inferences made from observations in helping scientists develop a model of the inside of the earth, however. One student, Rebekah, stated,

> *Scientists drill about ten miles into the earth and tell what they know about what they see from drilling. Then they do some other stuff, like set up machines that track waves during the earthquakes. When they do the earthquake measurement, the waves show that there has to be some kind of liquid in the middle of the earth because the waves don't go all the way through to the other side. They can't see the inside, but they know stuff from tests.*

Similarly, another student stated that scientists do make some guesses about what is inside of the earth, but these "guesses" were based on evidence:

> *Scientists guess about what is in the earth. Like, they guess that the inside of the earth is hot because lava sometimes comes out of the earth and it is hot.*

Thus, with the exception of the two students who recognized that evidence was used to make inferences about the inside of the earth, most students held contradictory views of the relationship of observation and inference, recognizing it sometimes in the case of the dinosaurs, but not in the case of the inside of the earth. Thus, it is questionable whether most students actually held informed views of observation vs. inference from these two questions. Perhaps a similar question targeting a context in which students made specific observations and inferences would better allow the students to distinguish between the two terms. It also raises the question of whether students' knowledge of observation and inference is specific to content area or to the particular contexts in which students actually made those observations and inferences.

The Creative and Imaginative NOS

The students described personal definitions of creativity and imagination. They tended to define imagination as something that was "not true." Six students responded in ways that indicated that imagination was "pretend." For example, one student explained that imagination was "like I can imagine I am a rock star and am singing to a lot of people. It is when I pretend." The other 17 students defined imagination as "when you dream something, or think about something in your head." One student said, "I can dream about being a dog, or a magic princess or a grown-up. Imagination is not true, but a dream." Another stated that "Imagination is when you think in your head. You can think about dancing or driving or running. You aren't really doing them, but you are thinking about them." Thus, their responses indicated that when someone is imagining it is not something that is "real."

Regarding the definition of creativity, 21 students responded in ways that illustrated their viewpoints of creativity as relating to art. For example, typical responses were "Creativity is when you put a lot of detail in your drawing" or "It is when you decorate things." Another typical viewpoint of creativity was that it is a piece of artwork that you do on your own, without help: "You make it yourself on your own." Two students responded in ways that indicated that they believed

creativity was more than just being artistic. One stated, “Creativity is when you use your mind—you focus your mind and it helps you figure stuff out.” The other stated, “It is when you create something new. Like you can think about something no one thought about before.” So these two students both described creativity as something to do with thought processes and not only artistic work.

Because most students (21) held inadequate definitions of scientific imagination and creativity, it follows that they did not believe that scientists used imagination and creativity in their work. One student simply stated, “How should I know what scientists do; I am just a kid!” Other students typically responded that you “can’t pretend things in science, so you can’t imagine stuff” and “Science is real. You have to do a real job; you can’t imagine things.” Regarding the use of creativity, students commonly responded “Sometimes you use creativity because scientists have to draw what they see” or “No, they just have to give the facts, not imagine the stuff”; however, the two students who had more informed views of creativity and imagination responded that scientists did use imagination and creativity in their work, one claiming that you “use your imagination in making a hypothesis, in creating experiments—you imagine what they will be like.” The other student stated, “Yes, they are creative in making inferences from their observations,” which also indicated this student had an understanding of these terms. Thus, when students held a more informed *scientific* definition of the terms “imagination” and “creativity,” they had a better view of how scientists used these in their own work.

The Tentative NOS

Four students responded that science does not change. One typical response was “Science never changes. It is put in the books so we can learn it.” Another said, “Books are not going to change because science doesn’t change.” Sixteen students indicated that they thought science did change, with 11 of those students stating that science does change with better technology. For example, one student stated, “If we get better technology, we know more stuff, so we can add it to the books.” Another typical response was “Scientists learn more with technology, so they change the books.” Thus, even with a technology explanation, the change that students were describing was “adding on” new information to science.

There were four students who responded in ways that indicated a more informed view of the tentative NOS. These students’ responses indicated that scientific evidence was used to develop scientific ideas, which could change with new evidence. For example, one student stated, “You make predictions and do a study. You get information from that study. Then, you change your ideas. Then you can write it in the book.” Another stated, “Well, you find new evidence all the time, so science changes.” The third stated, “Science changes, so you have to change the books to be the same as what you found out in science.” The final student said, “Of course the books will change in the future because science changes.”

Discussion and Recommendations

Similar to the older students in prior studies (e.g., BouJaoude, 1996; Griffiths & Barman, 1995; Khisfe & Abd-El-Khalick, 2002; Meichtry, 1993), the fourth graders in this study did not have conceptions of NOS that were in line with the recommendations of the reforms (AAAS, 1993; NRC, 1996) for the aspects explored in this study. Not surprisingly, the fourth graders held misconceptions regarding

the distinction between observation and inference, believing that scientists did use evidence to make scientific claims, but that generally there needed to be direct observation using the senses, or extensions of those senses, to make the claim. For instance, though the students recognized that scientists did not need to see dinosaurs to know they existed, they believed scientists relied on putting together all of the bones to build a picture of the dinosaur. With the exception of one student, they failed to recognize the role of indirect evidence when scientists determined possible colors of dinosaurs. The example of the interior of the earth further illustrates the emphasis the fourth-grade students place on direct evidence by their indicating that scientists had seen the inside of the earth with their own eyes, or with extensions of their senses through special technology. Thus, though students recognized the role of direct observation, they did not display an understanding of inferences made from indirect observations.

Fourth graders' definitions of creativity and imagination were consistent with everyday definitions of the terms. Similar to the findings of Khisfe and Abd-El-Khalick (2002), the fourth graders identified creativity with being artistic, and with imagination as "pretending something that is not real." Generally, these students believed scientists did not use imagination and creativity because science did not use art, and that because scientists seek the truth, they could not use their imaginations because that is not real.

Most students also held misconceptions of the tentative NOS, believing that science never changes because once you find something out you are "done." Half the class did indicate that technology could cause science to change because you could get more information from the technology. Thus, when students did believe science changes, it was an "add-on" view, not that scientific claims could change that much.

The results of this study provide further evidence that inquiry science instruction does not implicitly teach NOS conceptions that are consistent with views recommended in the reforms. The teacher of the students interviewed for this study approached her science instruction through inquiry, and intended that this approach would help her students develop informed views of the distinction between observation and inference, tentativeness, and the creative and imaginative NOS (see Akerson & Abd-El-Khalick, 2003); however, similar to studies of older school-age students, inquiry instruction in science does not necessarily enable students to develop better understandings of NOS (Khisfe & Abd-El-Khalick, 2002; Meichtry, 1993). Other studies have found that when the teacher explicitly helps students recognize how what they are doing in their scientific inquiry investigations in their classes is similar to what scientists do (e.g., explicit NOS instruction bridging the classroom to the practice of scientists), students will improve their NOS conceptions of the emphasized aspects (Khisfe & Abd-El-Khalick, 2002; Smith 2000). From this study, we recommend that teachers use explicit NOS instruction within a scientific inquiry instruction program. By explicit instruction, we mean that the teacher points out to the students when NOS aspects are being emphasized in an inquiry science lesson such as asking students to reflect on whether their results mean their work is "done," and emphasizing to them that, yes, they do have evidence indicating a specific explanation may be accurate, but that there may be competing explanations, or they may reinterpret the evidence or collect more evidence that would cause them to change their claims. By helping students to realize that their own scientific claims are tentative, and then explicitly asking them to relate what they did to what scientists do, there is a better chance that they will develop improved NOS conceptions (Khisfe &

Abd-El-Khalick, 2002; Smith et al., 2000). Perhaps with support through explicit instruction these fourth graders would have improved views of the emphasized aspects of NOS. We recommend studying the influence of explicit NOS instruction on fourth graders' views of NOS; however, from the results of this study, we do know fourth graders' typical NOS conceptions.

Another recommendation is that for teachers to help elementary students have NOS conceptions that are in line with national reforms, we must first understand what students already know about nature of science. Teachers must themselves have an understanding of the NOS conceptions as recommended in the reforms, and must know their students' conceptions so they can then plan explicit instruction to help improve those identified ideas, as they would with any science content. To improve understanding, teachers must first identify misconceptions. Further studies exploring elementary students' conceptions of NOS can help teachers know typical ideas held by elementary students, so they can plan instruction to improve those understandings. We can then explore the developmental appropriateness of the recommended target views of NOS (Abd-El-Khalick, 2002).

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Appendix

Modified VNOS-B

1. You read about a lot of things in your science books. Do you think that the things you learn from your science books will change in the future?

   Please circle one: Yes [Please answer part (a) if you circled "yes."]

   No [Please answer part (b) if you circled "no."]

   a. If you circled "yes," please explain why you think what you learn in science will change in the future.

   b. If you circled "no," please explain why you think what you learn in science will not change in the future.

2. Scientists believe that the dinosaurs lived more than 65 millions years ago.

   a. How do scientists know that dinosaurs really existed?

   b. How do scientists know what the dinosaurs look like (for example, the color of dinosaur skin, the shape of dinosaur eyes)?

3. a. What does the inside of the earth look like? You can draw a picture to show what the earth looks like on the inside.

   c. How do scientists know what the earth looks like on the inside?

4. a. What does the word "imagination" mean to you? Give an example.

   b. What does the word "creativity" mean to you? Give an example.

5. Do you think scientists use their imagination and creativity when they are doing scientific investigations?

   Please circle one: Yes [Please answer part (a) if you circled "yes."]

   No [Please answer part (b) if you circled "no."]

   a. If you circled "yes," please explain how you think scientists use imagination and creativity when they are doing scientific investigations.

   b. If you circled "no," please explain why you think scientists do not use imagination and creativity when they are doing scientific investigations.